CLINICAL ARTICLE

Impaction Bone Grafting with Low Dose Irradiated Freeze-Dried Allograft Bone for Acetabular Reconstruction

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Objective: Reconstruction of acetabular defects has been extremely challenging in both primary and revision total hip arthroplasty (THA). Impaction bone grafting (IBG) can restore the acetabulum bone mass and anatomically reconstruct the acetabulum. Our study aimed to report the short and medium-term clinical and radiographic outcomes of IBG for acetabular reconstruction in the cemented THA in the Chinese population.

Methods: This was a single-center retrospective review enrolling 57 patients between May 2013 and July 2019. The patients with acetabular defects were treated with IBG, using low dose irradiated freeze-dried allograft bone with or without autograft bone, in the cemented THA performed by one senior surgeon. Harris hip score (HHS), standard pelvis anterior–posterior radiograph and lateral hip radiograph were obtained before operation and at 1 week, 3 months, 12 months, and yearly. Graft osteointegration was evaluated by Oswestry's criteria, and complication was documented at the last follow-up. Independent sample ANOVA test and Pearson chi-square tests are used for statistical analysis.

Results: There were 61 hips in 57 patients. The average follow-up time was 35.59 months (5–77 months). According to AAOS classification, a total of 18 hips were identified as segmental bone deficiency (type I), with 21 and 22 hips for cavitary bone deficiency (type II) and the combined bone deficiency (type III), respectively. The average HHS was improved from 44.49 (range: 32–58) preoperatively to 86.98 (range: 78–93) postoperatively. Graft osteointegration was satisfactory (Oswestry score ≥2) in all patients. No dislocation occurred in the 57 patients (61 hips) during follow-up. Although one cup migrated, no revision, re-revision, radiographic loosening, graft bone lysis, or postoperative complications were detected at the final follow-up.

Conclusions: IBG with low-dose irradiated freeze-dried allograft bone in acetabular bone defect reconstruction is a reliable technique for restoring acetabular bone defects in THA.

Key words: Acetabular bone defect; Acetabular reconstruction; Impaction bone grafting; Low dose irradiated freeze-dried allograft bone; Total hip arthroplasty

Introduction

Total hip arthroplasty (THA) is heralded as the operation of the century.[1] Acetabular bone defects are challenging in both primary and revision THA. Surgical techniques for acetabular reconstruction includes superior placement[2] or medialization[3] of the hip center of rotation, structural bone grafting,[4] metal acetabular augments,[5] reinforcement ring[6] and impaction bone grafting (IBG). IBG is a well-established technique for restoring acetabular defects in THA.[7] It involved the use of autografts or allografts bone impacted into defects and metal meshes to convert uncontained defects into contained ones.[8] Compared with other

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techniques, the important advantage of IBG is that it can restore bone stock through osteointegration and therefore facilitates future revisions, especially for younger patients.[9,10] Combined with a cemented cup, the technique can reconstruct the bone bed to provide immediate biomechanical stability and permit early weight bearing.[11]

IBG is a well-established surgical technique pioneered by the Nijmegen[12] and Exeter[13] Group; a technique that can restore deficient acetabular bone stock and recreate anatomic center of rotation with a standard size acetabular socket even in Paprosky 3 and AAOS type III defects with favorable survivorships.[9,10,14–16] Due to aseptic loosening, the survivorship of acetabular components in IBG ranged from 100% at 10 years[17] to 85% after 20 years and 77% after 25 years.[18] Only by restoring bone stock, future revisions and re-revisions can be undertaken with ease. What is significant is that in addition to the patients who performed well clinically, and the radiographs showed excellent graft-host bone osseointegration, acetabular biopsies taken from animals and patients who received IBG for acetabular reconstructions showed evidence of revascularization and incorporation of the impacted morselized bone graft into host bone, making this technique especially valuable in the young arthroplasty patients.[19–22]

Most existing domestic Chinese literature on IBG focuses on developmental dysplasia of the hip (DDH) and revision hips.[23–25] Most authors use morselized fresh-frozen allograft bone in their IBG technique,[26,27] while others use irradiated freeze-dried allograft bone.[28] This is due to the advantages and disadvantages of different sources of bone grafting, such as a risk of disease transmission in allogenic freeze-dried bone and limited source of autograft bone. However, high-dose irradiated allogenic freeze-dried bone has the disadvantage of reduced biological activity and mechanical strength.[29] The freeze-dried bone adopted in the present study was irradiated at low doses (15 kGy) and had little effect on the biological activity and mechanical strength of the bone graft. Up to now, few clinical studies have directly compared autograft bone with low-dose irradiated freeze-dried allograft bone in cemented acetabular revisions.[30] Consequently, it is essential to evaluate the postoperative clinical and radiological outcomes of cases of IBG with grafted bone from diverse sources on bone defect reconstruction.

The primary intent of the present study is to evaluate the postoperative clinical and radiological outcomes of cases of IBG with low-dose irradiated freeze-dried allograft bone in acetabular bone defect reconstruction. The secondary objective was to share our experience using the IBG technique to reconstruct the hip joint anatomy. The clarification of the above objectives provides clinical guidance for selecting bone graft sources for acetabular anatomy reconstruction.

Methods and Materials

Inclusion and Exclusion Criteria

A single-center retrospective cohort study was adopted. This study protocol was approved by the Ethics Committee of the Second Xiangya Hospital (2019192). We included patients with large acetabular bone defects treated with the IBG technique in the cemented THA performed by a single senior surgeon between May 2013 and July 2019. The exclusion criteria were: (i) re-revision cases; and (ii) periprosthetic fracture cases. Based on the type of bone grafts used, patients were divided into three groups: autogenous bone, low dose irradiated freeze-dried allograft bone, and a hybrid of both.

Surgical Techniques

Operations were performed through the posterior approach. (i) Prepare the bone bed: the failed components were removed; a thorough debridement was performed until the healthy bleeding subchondral bone was visualized. The sclerotic bone around the acetabular rim should be drilled to promote vascular invasion into the graft. (ii) Fixed titanium mesh: sequential reaming of the acetabulum was performed using the transverse ligament as a guide, and any uncontained acetabular defects were covered with titanium mesh (Exeter Contemporary, Stryker, Newbury, UK) and anchored to the acetabulum with at least five AO self-tapping screws. (iii) Bone graft preparation: in primary THAs, the native femoral head would be used for IBG and supplemented with a low dose (15 kGy) irradiated freeze-dried allograft femoral heads (Beijing Xin Kang Chen Medical Technology Development Co. Ltd. Beijing, China) if there was insufficient autograft. In revision cases, irradiated freeze-dried allograft femoral heads were the primary source of bone grafts for IBG. The allograft should be immersed in complex iodine for 30 min and be washed with pulsatile lavage to remove the fatty marrow before being utilized. Cartilage and cortical bone are removed and prepared into 8–12 mm cancellous bone chips by rongeurs.[31] Vancomycin hydrochloride (1 g) was mixed with one allograft femoral head bone chips in addition to standard preoperative antibiotic prophylaxis according to previous cultures (if any). (iv) Impaction bone grafting and implant cemented cup: the prepared cancellous bone chips are impacted sequentially using specialized dome impactors (Stryker Orthopedics, Mahwah, NJ, USA), with the final impactor being at least 2 mm larger than the planned cup size. After meticulous impaction of the bone grafts, pulsatile lavage with a prodigious amount of sterile saline was performed, followed by irrigation with hydrogen peroxide solution to prepare the bone surfaces for cementing. Simplex (Stryker Howmedica, Newbury, UK) bone cement was used and pressurized into the prepared bone surfaces with a plastic seal, and a cemented cup (Exeter Contemporary Flanged Cup, Stryker, Newbury, UK) was implanted in all cases with a 45° of abduction and 15° of anteversion angle, with the pressure being maintained until the cement was fully polymerized (Figs 1 and 2). (v) Prepare and implant femoral prosthesis: we prepare the proximal femur and implant a suitable femoral prosthesis. (vi) Prosthesis assessment and wound closure: after the hip was repositioned, the joint stability and range of motion were evaluated and confirmed that no dislocation occurred during multiple directions and positions. The wound was then sutured in layers, and a drain was placed. (vii) Infection prevention and rehabilitation: Cefazolin sodium was continued for 24–48 h postoperatively to prevent infection.

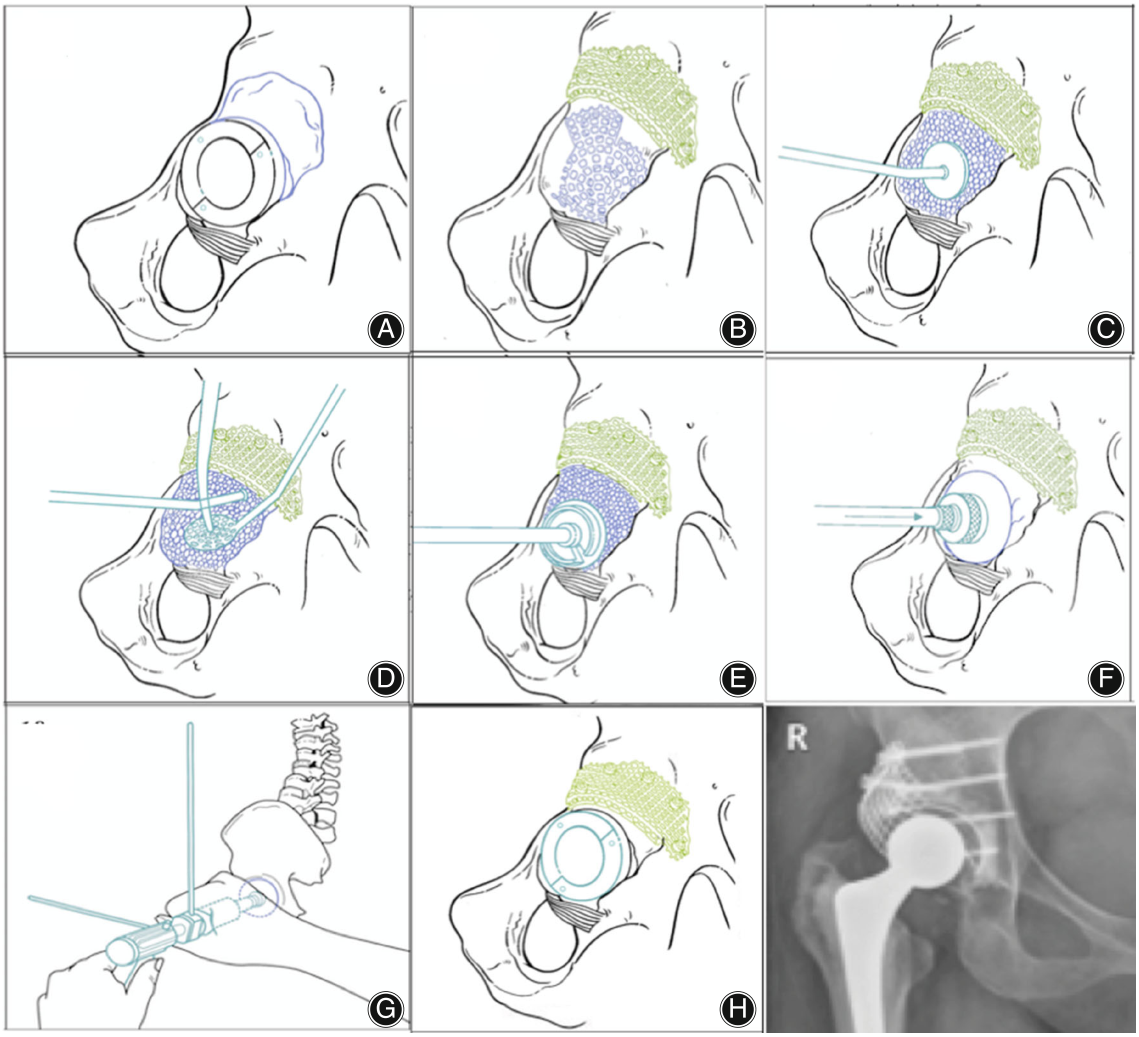

Fig. 1 (A–H) The manual sketch of critical procedures of the IBG technique. (A) The acetabulum was exposed. The original acetabular prosthesis was removed, and a cemented acetabular trial mold was placed to clarify the type and severity of the bone defect. (B) Transformation of segmental bone defects into cavernous bone defects using screw-fixed metal titanium mesh. (C–E) Filling the acetabular defect cavity with bone graft chips. The acetabular impactor is used from small to large to compress the bone graft chips. (F–H) The bone bed is dried using hydrogen peroxide gauze, filled with bone cement, and installed with the cemented socket cup

Mechanical anti-thrombotic prophylaxis and oral anticoagulation agents were administered for 1 month. Two weeks of bed rest was required for all patients after the operation. Toe-touch weight-bearing was allowed for the first 6 to 8 weeks, progressing to full weight-bearing after 12 weeks, depending on the degree of acetabular defects and radiographic findings.

Outcome Measures

The preoperative acetabular bone defect was classified using the American Academy of Orthopedic Surgeons (AAOS) classification. Harris hip score (HHS) and standard pelvis anterior–posterior pelvic and lateral hip radiographs at 1 week, 3 months, 12 months, and yearly were obtained. Oswestry's criteria were used to assess the graft osteointegration and trabecular remodeling within the grafted area at the latest follow-up.[32] Radiolucency was evaluated in the three zones of DeLee and Charnley, and a line of more than 2 mm width was considered positive for loosening.[33] Radiological failure of the cup was defined as a progressive radiolucent line in all three zones on the plain film or migration of more than 5 mm in any direction.[9,34] Functional outcomes were based on using HHS, and postoperative complications were recorded. Clinical failure was defined as any reason for the revision or re-revision of the acetabular component.

Statistical Analysis

Statistical analysis was performed with the SPSS for Windows, version 21.0 (IBM Corp, Armonk, NY, USA).

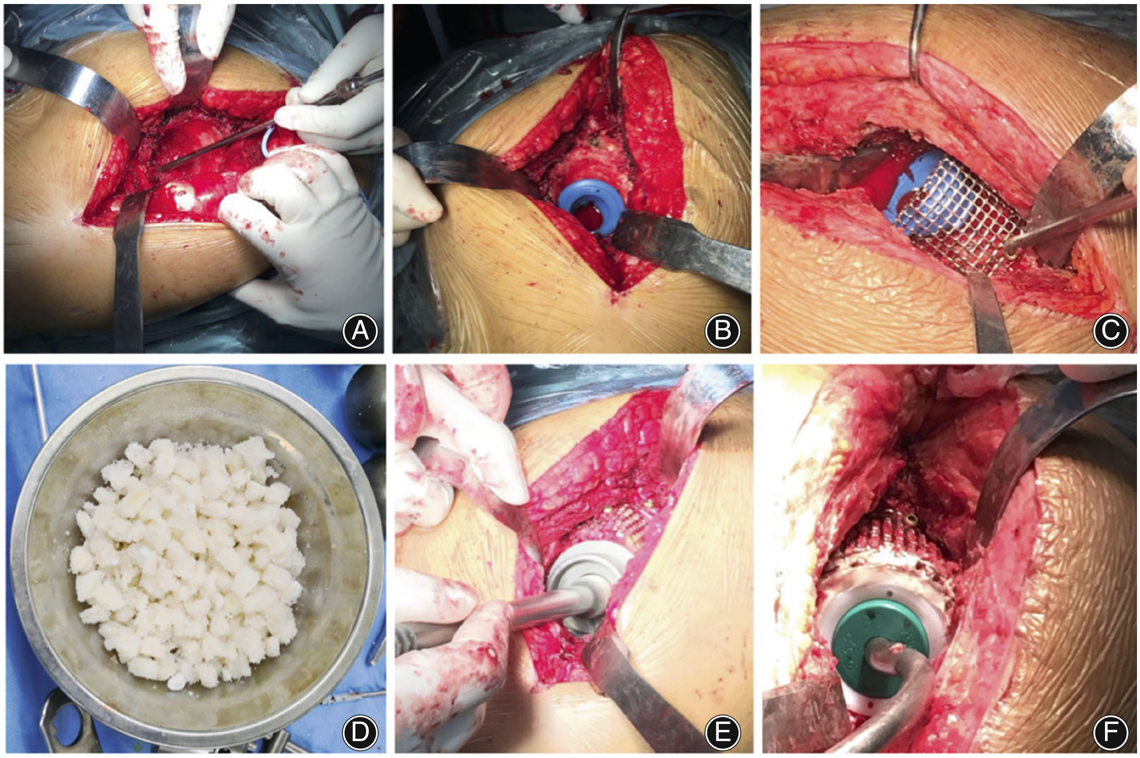

Fig. 2 (A–F) Primary and revision THA was performed *via* a standard posterior approach in this study. (A) Remove the acetabular component and completely expose the destroyed acetabular. (B) Place a standard trial acetabular cup to determine the volume size of the bone defect. (C) Transform a segmental bone defect into a cavernous bone defect by screwing in a titanium mesh. (D) Cartilage and cortical bone of the low dose irradiated freeze-dried allograft bone is removed and prepared into 8–12 mm cancellous bone chips by rongeur, and one femoral head is paired with 1 g vancomycin. (E) Stabilizing the bone graft using specialized dome impactors and vigorous impaction techniques. (F) The acetabular bone surface is rinsed and dried, and the cemented mortar cup is placed at 45°abduction and 15°anteversion angle

Qualitative variables were described as a ratio and compared between independent groups by applying the chi-square test. Quantitative variables were described as mean ± SD depending on their distribution as evaluated using the Student's *t*-test or the ANOVA test. *P*-value < 0.05 was considered to demonstrate statistically significant differences.

Results

Demographic Data

Fifty-seven consecutive patients with acetabular bone defects underwent primary THA (25 hips in 21 patients) and acetabular revision (36 hips in 36 patients) with an average followed up of 35.59 months (5–77 months) (Table 1). Among the revision THA, low dose irradiated freeze-dried allograft bone was used in 35 hips, and one patient received a hybrid of autograft bone and irradiated freeze-dried allograft bone due to contralateral femoral head necrosis and underwent THA. In the primary THA, an autograft femoral head was utilized in 17 of the 25 hips, while the remaining eight hips had a hybrid of autograft bone and low dose irradiated freeze-dried allograft bone.

Clinical Functional Assessment

The present study divided the 61 hips into three groups based on the different sources of grafted bone and assessed the functional scores for each group. In each group, the HHS improved from 44.49 ± 5.53 preoperatively to 86.98 ± 2.96 at the final evaluation ($P < 0.05$). However, results showed no significant differences among the three groups in terms of HHS (Table 1).

Radiological Outcome Assessment

Using preoperative radiographs and intraoperative records of the 61 hips (Table 1), there is evidence of bone graft incorporation without radiological signs of acetabular cup loosening in all cases except one hip in low dose irradiated freeze-dried allograft bone group, in which migration of the acetabular cup of less than 5 mm in the vertical direction was seen at the 5-year follow-up period. However, the patient was completely asymptomatic and was managed with

TABLE 1 Demographic data and outcomes of the patients undergoing primary or revision THA

Variables	Autograft bone gr.	Allograft bone gr.	Mixed gr.	Test statistics	*P*-Value
Mean age (years)	53.6 ± 10.8	62.7 ± 9.2	49.3 ± 7.9	$F = 9.810$	0.000
Gender (M:F)	4:13	14:21	3:6	χ^2=1.381	0.501
Mean BMI (kg/m^2)	23.9 ± 3.5	24.2 ± 3.1	23.5 ± 2.3	$F = 0.212$	0.810
Side L:R	8:9	21:14	6:3	χ^2=1.156	0.561
Pri-THA:Re-THA	16:1	1:34	8:1	χ^2=49.417	0.000
AAOS (Seg:Cav:Com)	12:2:3	3:18:14	3:1:5	χ^2=24.559	0.000
Mean HSS: pre-op	44.9 ± 6.7	44.3 ± 5.1	44.4 ± 5.3	$F = 0.059$	0.943
Mean HSS: post-op	87.4 ± 3.4	86.7 ± 2.7	87.6 ± 3.2	$F = 0.505$	0.606
Mesh: No mesh	15:2	17:18	8:1	χ^2=10.516	0.005
Mean F/U time (mths)	40.5 ± 23.2	33.7 ± 22.2	33.78 ± 25.9	$F = 0.541$	0.585
Osteointegration Stage 0:1:2:3:4:5	0:0:2:7:8:0	0:1:9:14:9:2	0:1:1:6:0:1	χ^2=11.382	0.181

Note: This table highlights all three groups had significant improvement in functional outcomes postoperatively, and no statistically significant differences were determined among the groups in osteointegration.; Abbreviations: BMI, body mass index; Cav, cavitary defect; Com, combine defect; F, female; F/U, follow-up; gr., group; HSS, Harris Hip Score; M, male; mths, months; Pri-THA, primary total hip arthroplasty; Re-THA, revision total hip arthroplasty; Seg, segmental defect

regular follow-up. Non-progressive lines were shown in all three zones on the plain film (Figs 3–5).

Graft bone osteointegration in the Oswestry classification was as follows: stage 1, $n = 2$ (3.3%); stage 2, $n = 12$ (19.7%); stage 3, $n = 27$ (44.3%); stage 4, $n = 17$ (27.9%); and stage 5, $n = 3$ (4.9%). However, no statistically significant differences were determined among the groups in osteointegration ($P > 0.05$).

Complications

Few perioperative complications were observed in the present study. A superficial hematoma occurred in one of the patients who underwent a two-stage revision in which drainage was performed. One patient had a displaced acetabular cup during follow-up. Fortunately, the patient was asymptomatic, had good hip stability and function, and did not require surgical intervention. Besides that, there were no revisions for acetabular cup loosening in either of the three groups. There was no postoperative dislocation, sciatic nerve injury, deep-vein thrombosis, or deep infection.

Discussion

Main Findings of the Study

The acetabular bone defect is still a colossal task in complex acetabular reconstruction. It is known that restoring acetabular bone stock and the center of rotation utilizing bone grafting is particularly important. The present study main found that IBG with either low dose irradiated freeze-dried allograft or autogenous bone showed favorable clinical and radiological outcomes in the medium term.

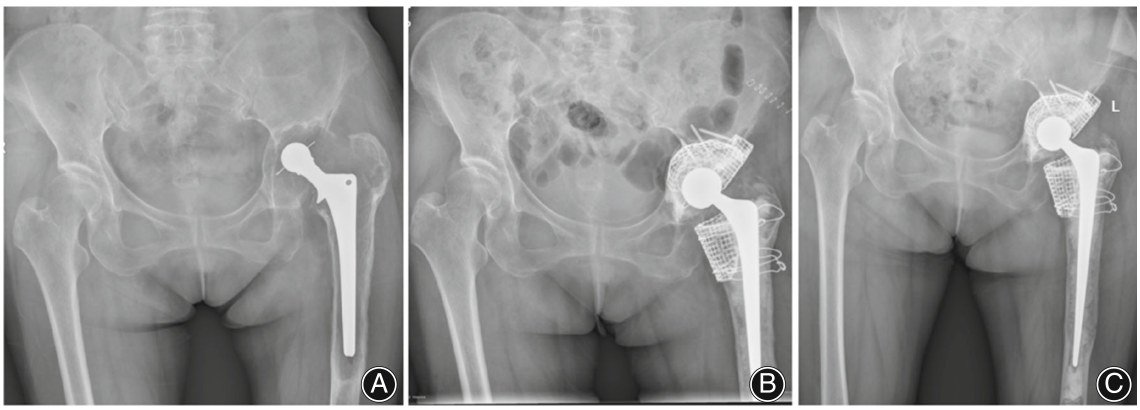

Fig. 3 (A–C) Preoperative and follow-up radiographs of the left hip joint in a 66-year-old woman. (A) The preoperative pelvic AP view of a female shows aseptic loosing and severe bone loss on both the acetabular and femoral sides. (B) Radiography at 1 week after she received a revision THR using IBG and meshes on both the acetabular and femoral side to restore the bone deficiency. (C) A radiograph at 12 months after the revision surgery on the left hip shows no radiographic loosening or cup migration.

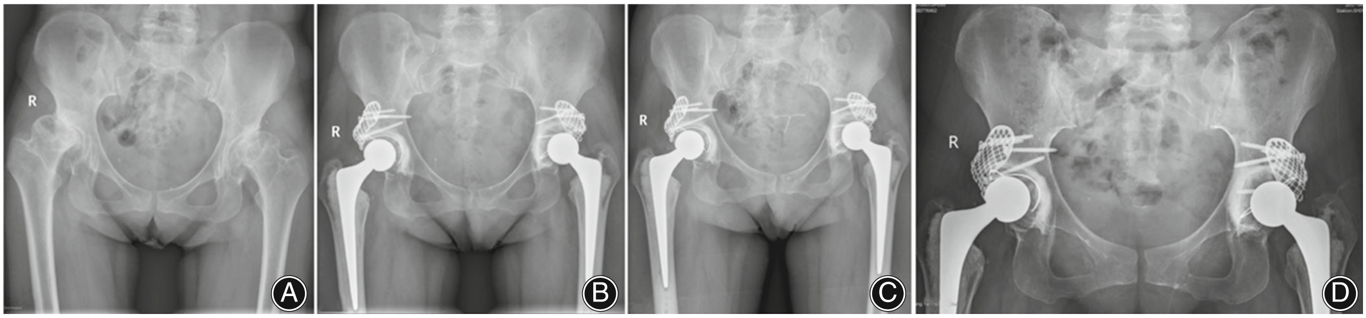

Fig. 4 (A–D) Preoperative and follow-up radiographs of the bilateral hip joint in a 44-year-old woman. (A) The preoperative pelvic AP view of a female shows an acetabular defect on both sides. The 44 year-old female had bilateral DDH, which leaded secondary hip osteoarthritis. (B) Radiography at 1 week after she received the second THR on the left hip and 10 months after the first surgery shows no radiographic loosening or cup migration. (C) Radiograph at 34 months after the first surgery on the right side and 24 months on the left side shows no radiographic loosening or cup migration. (D) Radiograph at 66 months after the first surgery on the right side and 56 months on the left side shows no radiographic loosening or cup migration

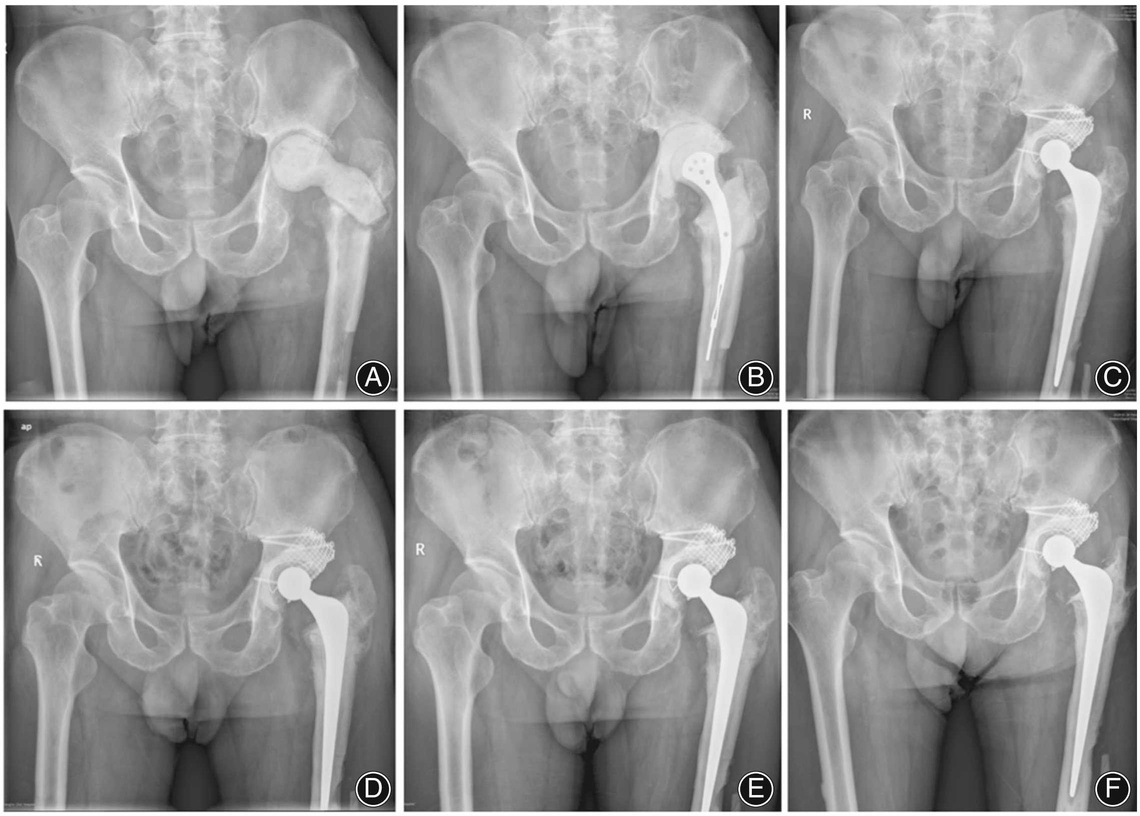

Fig. 5 (A–F) Preoperative and follow-up radiographs of the left hip joint in a 66-year-old male. (A,B) A 66-year-old male suffered a fracture of the left femoral neck 2 years ago. Radiography at 3 months after he received the first THR shows a failed spacer implanted in another hospital, and the infection is not under control, then underwent a hip debridement and implanted a new spacer in our hospital. (C) Radiography at 1 week after he received a revision THR using IBG and a mesh to reconstruct the acetabular defect on the left hip. (D–F) Radiograph at 24, 36, 60 months after the revision surgery on the left hip shows no radiographic loosening or cup migration

Effect of Bone Grafts in Restoring Bone Stock

There are several different types of bone grafts, namely autografts, fresh-frozen allografts, and irradiated freeze-dried allografts. Autologous bone grafts are still considered the "gold standard" as they fulfill all three ideal requisites of bone graft: osteoconductive, osteoinductive, and osteogenic without concerns about immunogenicity.[35] However, autografts have limited availability and are only suitable for repairing minor bony defects. In contrast, allografts are abundant in availability and do not incur any donor site morbidity but raise concerns about disease transmission. Allografts possessed osteoconductive but not osteogenic nor osteoinductive properties.[36] Their mechanical strength depends on the composition (cancellous, cortico-cancellous, or cortical), on the bone bank processing (fresh-frozen or freeze-dried, irradiated or not), and surgical handling (structural or morselized). Freeze drying reduces the mechanical properties of the bone graft compared to fresh-frozen samples.[37] Using fresh-frozen allografts, Schreurs reported 15-year survival rates for all-cause and aseptic loosening of the acetabular component to be 75% and 84%, respectively.[10] In comparison, using an irradiated freeze-dried allograft, Villatte *et al.* reported clinical and radiological survivorship of acetabular components at 10 years to be 96.2% and 84.5%, respectively. Irradiation further weakens the mechanical strength, especially at high doses.[38] Most tissue banks employ 25 or 60 kGy, and some experimental animal studies have demonstrated that irradiation bone graft with a lower dose of 15 kGy maintains bactericidal activity and does not affect mechanical or biological properties.[39] It is believed that the lower dose of bone irradiation did not affect the initial stability after impaction bone grafting compared to the high dose irradiation group and did not show a tendency to increase prosthetic micromotion.

Our Experience Using IBG to Reconstruct the Acetabulum

Our experience of IBG with morselized fresh autograft, low dose irradiated freeze-dried allograft bone, and a hybrid of them have shown favorable outcomes. At the latest follow-up, the mean HHS improved from 44.49 to 86.98 with no complications necessitating any revision. All patients had radiographic evidence of graft osteointegration and no radiological signs of acetabular cup loosening. There were no significant differences in implant survival, HHS, and graft incorporation among the groups who received a pure autograft bone, pure low dose irradiated freeze-dried allograft bone, and a hybrid of them for IBG. Cup migration was seen in one case at 5 years postoperative period. Possible causes include a massive cavitary defect in that patient and inadequate impaction of bone grafts. Research by Abdelnasser *et al.* concluded that a better anatomical center of rotation of the acetabulum could be obtained with the IBG technique and that there was less cement cup migration after reconstruction of AAOS type I and II bone defects than type III, and suggested that other options could be considered in acetabular reconstruction of these large acetabular bone defects.[40] Consequently, biological techniques should be used to reconstruct skeletal defects in cases with substantial bone defects to restore sufficient bone stock and normal anatomical center of rotation and obtain excellent clinical outcomes. Although a titanium mesh was used in all primary THA cases and some revision cases in the present study, there were significant differences in the types of bone defects and whether titanium mesh was used included in each of the groups; therefore, it was not possible to evaluate whether there were significant differences in osseointegration after impaction grafting between subgroups with different bone defect sources of grafted bone and whether titanium mesh was used.

Limitations

There are several limitations to our study. First, this is a retrospective cohort study from a single surgeon single-center series. However, the postoperative protocols are the same because it is a single-center and single surgeon series. Second, even though short and medium-term clinical and radiological outcomes were not significantly different in the three groups, mid to long-term follow-up would be necessary to evaluate the effect of this technique in our study population. We also do not have histologically proven graft osteointegration as the authors felt there was no need to subject patients to another surgery and anesthesia just for that purpose. IBG needs special instruments such as specialized dome impactors to impact the bone graft, and this technique is limited in the setting of pelvic discontinuity. The source and the availability of the bone grafts also present another limitation of this technique, and IBG is considered time-consuming and technically demanding with a high learning curve.

Conclusion

IBG with either low dose irradiated freeze-dried allograft bone is a reliable technique for restoring acetabular bone defects in THA. As the volume of total hip replacement surgery increases, the field of complex joint reconstruction faces many exciting challenges. While innovative techniques may help provide new solutions, restoring bone volume and reconstructing the center of rotation has been the gold standard for surgeons to pursue. In future clinical studies, we need to collect more cases of acetabular bone defect reconstruction using low-irradiation allogeneic freeze-dried bone type and perform longer clinical and imaging follow-up to further support its superiority.

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